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SIMULTANEOUS VALUES OF MAGNETIC DECLINATION AT DIFFERENT BRITISH STATIONS.

BY

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SIMULTANEOUS VALUES OF MAGNETIC DECLINATION AT DIFFERENT BRITISH STATIONS.

§ 1. HISTORICAL.

A MAGNETIC observatory can collect data for the future increase of scientific knowledge. This knowledge may incidentally prove to be of practical importance, but its immediate utilisation is seldom contemplated. There are, of course, always possible advantages in working up observational data promptly, because they may be affected by instrumental errors, and the detection and correction of such errors generally becomes more difficult as time passes. Also a study of data often suggests lines of research, and the opportunity of prosecuting these may never recur under such favourable conditions.

But, in addition, an observatory can collect data for immediate practical use, and rapidity in publication may be essential. Under normal conditions declination D is the magnetic element pre-eminent for practical applications; and, fortunately, it is easy in its case, even with photographic registration, to reach numerical results of high accuracy within a day or two of the occurrence of the event. This is due to the fact that the scale value is practically invariable; in the normal case changes of base value are small, and no allowance has to be made for changes of temperature. The operations necessary to supply a base value occupy only a few minutes; and in skilled hands, with weekly absolute observations, uncertainties of base value should not exceed a few tenths of a minute of arc. During the last two years the Meteorological Office has prepared for publication during the ensuing week two-hourly mean values of D at Kew Observatory for every day. These have appeared regularly in the Journal of the Institution of Mining Engineers. These two-hourly means are based on hourly values. At first the hourly values represented measurements made at the exact hours on smoothed curves. The old practice at Kew was to smooth the selected quiet day curves, when any irregularity presented itself, by drawing a freehand pencil line. With the increased development of electric railways, causing at most hours incessant small oscillations of the magnets, the smoothing had to be applied at most hours, even on the quietest of days. The smoothing of every day's curve is burdensome, and the application of the method to days of considerable natural disturbance has drawbacks. Much time may be spent, without an assurance being felt that the result is satisfactory; and when the process had to be applied in the Superintendent's absence—as was sometimes necessary for the weekly returns—by a less experienced hand, this aspect of the case became prominent.

Accordingly, since October 1919 use has been made of a mean-value scale. The operation takes longer than reading a smoothed curve and makes greater demands

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on the skill of the operator. But with ordinary curves the results with the mean-value scale are decidedly less arbitrary than those derived by smoothing. With very highly disturbed curves the two methods may be equally unsatisfactory, but on such occasions no method of correction is likely to render field observations valuable.

But for considerations of space, hourly values would have been published, as hourly measurements are taken. But the question has been raised more than once whether readings at exact hours G.M.T. would not be of more practical use than mean hourly readings. A surveyor, it has been urged, does not read his compass continuously for two hours, or even one hour. What he wants to know is the value of the declination at a specified minute. If he knew that such information would be available for exact hours G.M.T. he could take fundamentally important readings at the hour, or he could take several readings during five or ten minutes centering at the hour, and employ the mean of these for comparison with a five or ten minute mean ordinate.

The best procedure depends on at least two considerations. The first is the degree of accuracy really required by the engineer; the second is the degree of parallelism between the changes of D which occur simultaneously in different parts of the country. The latter question has been concerning me during the last two years, because of its bearing on the utility of the weekly publication of D results. If simultaneous D changes are widely different in different parts of the country, no single station can supply data satisfactory for general guidance.

The position in 1918, when the weekly publication began, was as follows: Magnetographs were in operation at Eskdalemuir, Stonyhurst, Greenwich and Kew. At Eskdalemuir there was full publication, some considerable time after the event, of hourly values of N, W and V (north, west and vertical components of force). Diurnal inequalities were given both for all days and for the international quiet days. D inequalities were also given as calculated from the N and W inequalities. Stonyhurst did not publish hourly values or diurnal inequalities. Greenwich published diurnal inequalities—the D inequality from a D magnetograph—for all except very highly disturbed days and for the international quiet days. Kew published diurnal inequalities for D and H (horizontal force) from quiet days only. Falmouth used to publish diurnal inequalities for the international quiet days, but had ceased registration in 1913.

A comparison of Greenwich and Kew quiet day curves for several months, carried out by Professor S. Chapman and myself, on the initiative of the Astronomer Royal and the Director of the Meteorological Office, had shown a close parallelism between the hourly values. But with observatories on naturally undisturbed sites only some twenty miles apart, this was almost certain *a priori*, assuming no serious disturbance of the regular diurnal variation due to electric traction near either station. It was, in fact, to test this latter possibility that the comparison was primarily made.

The diurnal inequalities that used to be published for Kew and Falmouth were not for individual months, but for the whole year and two half years, winter and summer (April to September). These seasonal inequalities were known to fluctuate very similarly from year to year, and to show no large differences between

the ranges at the two stations. A similar result was known to be true of the Eskdalemuir and Kew quiet day diurnal inequalities, but only one or two years' results were then available. Falmouth curves had been carefully examined at Kew on various occasions, and a few years after recording ceased at Falmouth, all the curves were removed and stored at Kew. A general survey of the Kew and Falmouth curves had shown a close parallelism. If there were an oscillation at Kew, a similar oscillation was recognisable at Falmouth. No striking disparity had been noticed in the amplitude of corresponding D movements at the two stations, but with 1 mm. of ordinate representing 1′·17 at Falmouth as against 0′·87 at Kew superficial inspection could give only a general impression of similarity.

The Eskdalemuir magnetographs which now record N and W were originally set up as D and H instruments, and some records from them in that state were obtained in 1908 and 1909. Great trouble was being experienced then from the dampness of the magnetograph room, and the instruments were being run only more or less tentatively. Thus the number of complete days' traces obtained was very limited, and the base line values somewhat uncertain. After 1909 no further D records were obtained at Eskdalemuir until 1919, when the D magnetograph previously in use at Falmouth was set up.

Though the elements being recorded at Eskdalemuir and Kew from 1910 to 1918 were different, assurance had been reached on one point, viz., that natural disturbance was greater at Eskdalemuir than at Kew. This is what might have been anticipated from the geographical positions, but the difference was greater than one would have expected.

Taking all known facts into account, it was anticipated in 1918 that at times of high disturbance even two-hour means from Kew would not apply very closely to collieries in Scotland, Wales or Northern England. Thus, as a protection to the user of the weekly data, " character " figures 0, 1 and 2—answering to quiet, moderately disturbed and highly disturbed conditions—were assigned to the individual days, and an asterisk with warning footnote was attached to all two-hour intervals which were highly disturbed.

§2. Results at Eskdalemuir, Stonyhurst, Falmouth and Kew.

Pending the running of a D magnetograph at Eskdalemuir, an attempt was made to utilise the limited material of 1908–9 by instituting a comparison between the amplitude of corresponding irregular movements there and at Kew. The Eskdalemuir movement proved to be invariably the larger, bearing to the corresponding Kew movement, on the average of a large number of cases, the unexpectedly large ratio 2·14:1.

Thanks to the courtesy of the late Reverend W Sidgreaves S.J. a loan was obtained of corresponding Stonyhurst curves for 1908-9. Measurements of the movements recorded in these and in Falmouth curves of the same two years gave the following mean values :—

(Stonyhurst movement) ÷ (Kew movement) = 1·68.
(Falmouth movement) ÷ (Kew movement) = 1·14.

It was noticed that the irregular movements at the four observatories during the winter of 1908-9 were fairly in harmony with the law—

$$\text{Range} = (\text{Range at Kew})\,(1 + 0{\cdot}23\,\Delta\lambda + 0{\cdot}10\,\Delta l),$$

where $\Delta\lambda$ and Δl are the north latitude and west longitude of the station relative to Kew, measured in degrees. An increase of disturbance in a north-westerly direction, i.e., as an approach is made towards the magnetic pole in the northern hemisphere, appeared very reasonable, in view of the increase in that direction of auroral frequency. It was also to be expected on any theory such as Birkeland's and Störmer's, which attributes aurora and magnetic storms to electrical discharges from the sun, the phenomena on the earth being largely determined by the earth's own magnetic field. There appeared some indications that during the summer months of 1908 and 1909 the differences between the different stations were reduced, and attention was called to this. General considerations also suggested that the ratio of the movements at two stations might vary sensibly with sunspot frequency, because an earlier investigation had shown that the range of the regular diurnal inequality showed a greater variation with sunspot frequency at some stations than others.

§ 3. Difference Inequalities for Eskdalemuir and Kew.

If time had been of no account and circumstances had permitted, the present investigation might with advantage have included a comparison of simultaneous values—not merely mean hourly values—and for H as well as D. Information as to V changes is in one way less pressing, because in ordinary latitudes V is a much quieter element than D or H. A comparison of instantaneous values at Eskdalemuir and Kew throughout the whole 24 hours has ceased to be possible owing to the artificial disturbances at Kew. It is one of the things that might have been done if a D magnetograph had been in operation at Eskdalemuir 20 years, or even 10 years ago.

An unexpected obstacle to the enquiry was an apparent variability in the base line values of D at Eskdalemuir. This could not affect the diurnal inequalities or the measurements of the irregular movements presently to be discussed, and could hardly influence seriously the comparison of hourly values throughout one and the same day. But in some of the months it prevented satisfactory comparison of hourly results derived from different days. It had been originally intended to confine the comparison to Eskdalemuir and Kew, but some of the results obtained for 1919 proved so different from those deduced for 1908-9 that confirmation seemed essential. Thanks to the courtesy of the Reverend A. L. Cortie, S.J., a number of Stonyhurst D curves for 1919 were put at my disposal. These suggested the expediency of extending the enquiry over a period of years, and this was done by utilising Falmouth curves from 1908 until the suspension of registration in 1913. To have included a whole 11-year period would have had advantages if time had allowed.

The curves received from Eskdalemuir covered most days of July, August, October, November and December, 1919. There were also a few curves for June and September. Hourly measurements of all these curves had been made at Eskdalemuir with a mean-value scale, and the results were kindly communicated by Dr. Crichton Mitchell. These measurements were utilised in calculating some of the difference inequalities which appear in Table I.

It may be well to explain what is meant by a difference inequality. Suppose we have two ordinary inequalities it may be from the same set of days at two different stations, or from two sets of days at the same station, then the difference inequality is

what is got when each hourly value in one of the inequalities is subtracted algebraically from the corresponding hourly value in the other inequality.

TABLE I.—DIFFERENCE INEQUALITIES.

Hour G.M.T.	A	B	C	D	E	F	G	H
	′	′	′	′	′	′	′	′
1	−0·33	−0·01	−0·26	−0·12	−0·89	−0·06	−0·17	−0·71
2	−0·05	−0·23	−0·44	−0·07	−1·00	+0·17	−0·13	−0·54
3	+0·10	−0·20	−0·41	−0·67	−0·59	+0·15	−0·53	−0·66
4	0·00	−0·31	−0·58	−0·36	−0·35	−0·28	−0·44	−0·34
5	−0·16	−0·08	−0·22	−0·19	−0·14	−0·43	−0·54	−0·76
6	−0·18	+0·02	−0·07	+0·10	+0·80	−0·42	−0·14	−0·51
7	+0·14	+0·12	+0·29	+0·64	+1·44	−0·20	+0·01	−0·08
8	+0·16	+0·30	+0·36	+0·36	+1·12	−0·14	+0·06	−0·24
9	+0·15	+0·18	+0·44	+0·12	+1·32	−0·33	−0·22	−0·41
10	+0·09	+0·05	+0·35	+0·45	+1·83	−0·17	−0·45	−0·24
11	−0·08	−0·28	−0·05	−0·29	+0·64	−0·26	−0·66	−0·25
12	−0·13	−0·09	+0·09	−0·21	+0·54	−0·17	−0·36	−0·07
13	+0·03	−0·05	+0·04	+0·03	+0·72	+0·24	−0·08	+0·19
14	+0·21	+0·04	+0·26	+0·24	+1·23	+0·21	+0·23	+0·38
15	+0·23	+0·21	+0·44	+0·57	+2·01	+0·32	+0·47	+0·49
16	+0·11	+0·19	+0·23	+0·93	+2·76	+0·35	+0·58	+0·92
17	+0·02	+0·12	+0·26	+0·77	+1·75	+0·28	+0·62	+0·73
18	+0·08	+0·06	+0·29	+0·47	−0·79	+0·16	+0·48	+0·80
19	+0·07	+0·17	+0·18	+0·08	−1·25	+0·11	+0·50	+0·74
20	+0·04	+0·06	+0·21	−0·27	−2·29	+0·08	+0·34	+0·24
21	−0·04	−0·16	−0·27	−1·18	−3·38	+0·05	+0·29	+0·29
22	−0·22	−0·21	−0·39	−0·43	−2·01	+0·11	+0·24	+0·17
23	−0·05	+0·04	−0·36	−0·74	−2·14	+0·19	−0·04	−0·08
24	−0·20	+0·08	−0·20	−0·16	−1·36	+0·04	−0·09	−0·17

The various difference inequalities in Table I are distinguished by letters. A is the Eskdalemuir-Kew difference inequality from international quiet days for the winter season (January, February, November and December). It is a mean from the four years 1913-1916. There being five quiet days a month, it is based on 80 days. B is also an Eskdalemuir-Kew difference inequality. It employed all the complete days of October, November and December, 1919, to which character 0 had been assigned in the weekly lists mentioned above. Some of the days included would probably have got character 1 if Eskdalemuir conditions had been taken into account. As 31 days were included, in spite of the fact that some quiet days had to be omitted owing to breaks in the Eskdalemuir record, the average day represented decidedly more disturbance than the average international quiet day. C and D are Eskdalemuir-Kew inequalities for the same months as B, but refer respectively to the 31 complete days allotted character 1, and the 12 complete days allotted character 2 in the Kew lists. E refers to the Kew only. It represents the algebraic excess of the hourly figures in the inequality from days of character 2 over the other days of the three months October to December, 1919. The reason for forming this particular difference inequality is that days of character 2 are excluded from the inequalities published in the "Mining Engineer's Journal."

The remaining inequalities are all Eskdalemuir-Kew difference inequalities, and all refer to summer months. F refers to the 80 international quiet days for summer (May to August) from the four years 1913 to 1916. G and H refer to the combined months of July and August, 1919, G being from 21 days of character 0, and H from 14 days of character 1. The hourly values derived from smoothed

Kew curves were accepted for G, as the precise way of measuring days of character 0 could make but little difference, but for H a new set of measurements was made with the mean-value scale. The number of days of character 2 in July and August, 1919, did not warrant the calculation of an inequality. The ranges of the inequalities based on the international quiet days were :—

Winter—Eskdalemuir 3′·60 ; Kew 3′·35, Eskdalemuir-Kew 0′·56
Summer— ,, 10′·24 ; ,, 9′·80, ,, 0′·78

The excess of the Eskdalemuir over the Kew range is in both cases trifling. It is, however, substantially exceeded by the range of the difference inequality. This is due, at least partly, to the difference in local time. Eskdalemuir is 2° 53′ west of Kew. Thus the Eskdalemuir inequality will naturally have a lag of $11\frac{1}{2}$ minutes as compared with Kew. This diminishes the excess of Eskdalemuir over Kew declination during the hours immediately preceding the maximum between 13h. and 14h. and increases it during the hours immediately following the maximum. Thus in A the excess of 0′·36 in the entry at 15h. over the entry at 12h. is not really surprising. The same phenomenon would be seen and to a larger extent at any station in the Welsh coal field.

The difference inequality B as might be expected, is less regular than A, but has a similarly small range. The difference inequalities C and D, with ranges of 1′·02 and 1′·57 respectively, are also somewhat irregular. But there is obviously a general resemblance between A, B, C and D, showing a progressive development in the difference between Eskdalemuir and Kew. Their resemblance to the Kew difference inequality E suggests what I think is the true explanation, viz., that disturbance exerts a greater influence at Eskdalemuir than Kew. At both stations disturbance, as shown by E, tends to increase westerly declination during the central day hours, and to depress it during the corresponding night hours. The only striking difference of type between D and E is the occurrence of negative values at 11h and 12h in D, and this, as we have seen, arises from the difference of local time.

The ranges of the Eskdalemuir-Kew inequalities in the summer months, 0′·78 in F, 1′·16 in G, and 1′·68 in H, are considerably larger than the corresponding ranges for winter months, but they represent a decidedly smaller percentage of the corresponding Kew or Eskdalemuir ranges.

Diurnal inequalities are independent of the accuracy of the absolute observations. Apart from accidental irregularities, which it may require a very large number of days to eliminate, the only possible sources of error are mistakes as to the scale value, or faulty behaviour of the magnetograph. The *D* scale value depends essentially only on measurements of length, and it is difficult to see how with an Adie instrument an error as large as one per cent. can arise if reasonable care is used. The only reasonably likely cause of misbehaviour of a declination magnetograph is friction exerted on the magnet, e.g., by a hair or spider web extending from it to the damper. The glass cover should be adequate protection against spiders. A hair might undoubtedly act as a drag reducing all movements regular and irregular. If, however, its resistance acted jerkily, as one would expect, the appearance of the curve should show that something was wrong, and in any case unless the defect were very trifling it could not long escape detection through the irregularity in the results obtained for the base values.

§ 4. Uniformity of Secular Change at Eskdalemuir and Kew.

We now come to a possibility that must be taken into account, viz., that the diurnal inequalities at two stations may agree and yet the absolute values may change unequally. There might, for instance, be a difference between the rates of secular change; or, while the aggregate change for the whole year was identical, or nearly so, the rate of change might show a marked annual inequality, which was not the same at the two stations.

Table II is intended to throw light on this point. The last column gives the difference between the mean annual values of D at Eskdalemuir and Kew from 1911 to 1916, the Eskdalemuir value being the larger. It also shows how the difference between the mean Eskdalemuir and Kew values for the individual 12 months

Table II.—Differences between Mean Monthly and Yearly Values of Declination at Eskdalemuir and Kew.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly Mean.
	′	′	′	′	′	′	′	′	′	′	′	′	° ′
1911	−0·1	−1·3	+0·1	−0·2	+0·6	0·0	+1·2	−0·7	+0·2	+0·3	−1·4	+0·8	2 17·1
1912	−0·6	0·0	−0·3	+0·1	−0·3	+0·1	−0·5	−0·6	−0·2	+0·8	+0·3	+0·2	2 17·4
1913	−0·4	−0·9	+1·2	−1·2	−0·6	+1·8	+0·2	−1·0	−0·4	−0·2	+0·8	+0·5	2 17·9
1914	+0·5	−0·1	−0·4	+0·7	−0·1	−1·1	−0·7	−0·0	0·0	0·0	+0·5	+0·4	2 17·5
1915	+0·1	−0·1	−0·4	+0·6	+0·4	+0·4	+0·3	−0·6	+0·2	−0·3	+0·4	0·0	2 17·5
1916	−0·1	0·0	+0·3	−0·1	+0·3	−0·8	−0·7	−0·7	−0·1	+0·4	+0·5	−0·1	2 17·3
Mean	−0·1	−0·4	+0·1	0·0	0·0	+0·1	0·0	−0·6	0·0	+0·2	+0·2	+0·3	2 17·4

of each year differs from the yearly mean difference. For instance, the −0′·1 at the top of the January column signifies that the mean value of D at Eskdalemuir in January, 1911, exceeded the corresponding Kew mean by 2° 17′·1−0′·1 or 2° 17′·0.

The Eskdalemuir means were derived from all days of the year, with the exception of a very few—mostly days of very large disturbance—for which the records were incomplete. The Kew means, on the other hand, were derived from the international quiet days, five a month. Even at the same station we should not expect absolute identity between all day and quiet day means. There is no marked tendency in D, as there is in H, for all day and quiet day means to differ in a definite direction, but apart from accidental causes the mean quiet day seldom falls absolutely at the centre of the month.

The figures in the last column of Table II show that in the period in question the secular change—which averaged about 9′·5 per annum—was closely the same at the two stations. The last line shows that there was little if any trace of an annual inequality of the D difference. The mean of the monthly differences taken irrespective of sign is only 0′·46. 1913, a very quiet year and the year of sunspot minimum, shows the largest fluctuations. The probable explanation is that owing to building operations the Kew magnetographs had to be dismounted and run under less favourable surroundings than usual. Omitting 1913 the mean difference is reduced from 0′·46 to 0′·39.

Observations ceased at Falmouth in 1913. Results for the Falmouth-Kew declination difference analogous to those in Table II were got out for 1911 and 1912,

but are not reproduced. Though both sets of D means were based in this case on the international quiet days, the fluctuation in the difference was rather larger than for the same years in Table II. Still the general outcome was the same.

§ 5. Comparison of Mean Daily Values at Eskdalemuir and Kew.

It seemed a natural inference from Table II that if the D difference between Eskdalemuir and Kew shows at times a tendency to an irregular fluctuation in one direction, whether an increase or a decrease, such tendency must either be very slight, or must undergo reversal before many days elapse. This, however, is such a vital point that more direct evidence appeared essential. Accordingly absolute mean values were got out, so far as possible, for each day of 1919 for which Eskdalemuir data were available. Table III shows in the columns headed B how the excess

Table III.—Eskdalemuir-Kew Mean Daily Values (Departures from Monthly Means).

Date.	June.		July.		August.		September.		October.		November.	
	A	B	A	B	A	B	A	B	A	B	A	B
		′		′		′		′		′		′
1	..	..	0	−0·5	1	+0·1	0	0·0	2	−0·1	..	..
2	..	..	0	+0·1	1	−0·4	1	+0·7	2	−0·6	..	..
3	..	..	0	−0·8i	0	−1·0	0	+0·1	1	+0·6	..	..
4	..	..	0	−0·7i	0	−0·4	0	+0·3	2	+0·4	..	..
5	..	..	0	−1·6i	0	−1·0	0	+0·3	2	+0·7	..	..
6	..	..	..	..	0	−0·2	1	+1·9	2	+0·4	..	..
7	..	..	0	+0·3i	1	−0·6	1	−0·2	1	+0·6	..	..
8	..	..	1	−1·5i	0	+0·2	0	−0·2	1	+0·1	..	..
9	..	..	1	−0·5i	0	0·0	1	−0·4	1	+0·7	..	..
10	..	..	0	−0·6	0	−0·5	1	−0·9	1	+0·2	0	+0·4i
11	..	..	0	−0·4	2	+1·4i	0	−1·3	1	+0·3	2	+0·9i
12	..	..	0	−0·4	2	+0·1	0	−0·3	0	−0·6	2	+0·4
13	..	..	0	−1·0	0	−0·2	..	..	0	−1·0	0	+0·3
14	..	..	0	+0·3	0	−0·3	..	..	0	−0·8	0	+0·2
15	..	..	0	0·0	0	+0·5	..	..	1	+0·3	0	+0·1
16	..	..	0	+0·4	1	−0·1	..	..	2	+0·4	2	−0·1
17	..	..	1	+1·0	1	−0·6	..	..	2	+0·6	2	−0·3
18	..	..	1	+0·8	0	+0·7	..	..	1	+0·4	2	−0·3
19	..	..	0	−0·1	1	+0·7	..	..	0	−0·2	0	−0·1i
20	..	..	0	−0·4	1	+0·9	..	..	0	−0·9	0	−0·4i
21	..	..	0	+0·4	0	+1·1	..	..	0	−0·6	1	−0·5
22	..	..	1	+0·4	0	+0·5	..	..	..	..	1	+0·4
23	1	0·0i	1	+1·0	0	−1·0i	..	..	..	..	1	−0·4
24	0	−0·2	0	−0·1i	0	−0·9i	..	..	..	..	1	−0·1
25	1	−0·3i	..	..	0	−0·8	..	..	..	..	1	−0·2
26	1	+0·4i	0	+0·6i	1	−0·2	..	..	..	..	1	−0·4
27	0	+0·7	0	+0·4i	0	+0·1	..	..	..	..	0	−0·3
28	0	−0·3	0	+0·8	0	−0·3	..	..	..	..	0	−0·2
29	0	−0·4	0	+0·3	0	+0·4	..	..	..	..	0	+0·3
30	0	+0·3	0	+0·8	0	+0·2	..	..	..	..	1	+0·2
31	..	..	0	+0·3	0	+0·7	..	..	..	..	..	..
Arithmetic Means		0·4		0·5		0·5		0·5		0·5		0·3

of the Eskdalemuir mean daily values over the corresponding Kew values differed from the mean excess for all days of the month. The columns headed A give the

character figures as published in the Kew weekly lists. Days when more than two-hourly values were lacking at Eskdalemuir have the letter *i* attached, to show they were incomplete. The (arithmetic) means in the last line are derived from the complete days only. Most of the incomplete days lacked either the forenoon or the afternoon hours, so in their case the difference between the diurnal inequalities shown in Table I would naturally have some influence.

The Kew base value was treated as invariable throughout each month. At Eskdalemuir in June a change of 1′·2, deduced from two base values before and five after the event, was accepted as a consequence of a definite instrumental change. The Eskdalemuir July base values, 30 in number, suggested a progressive change of about 1½′. This was accepted as real, and separate base values were applied for each group of five days. In view, however, of later events some doubt may be felt as to the reality of this change.

It is rather significant that if the base value at Eskdalemuir were treated as invariable throughout the whole of July, the mean in the last line of Table III would be reduced from 0′·50 to 0′·37. The August base values, 19 in number, suggested a change of about 1′·2 at Eskdalemuir in the course of August, but nearly the whole of it seemed to appear while a new instrument was being set up in the room. In September there were only five base value observations, indicating a large fall of base value between the 5th and the 9th. The reality of a big change was beyond doubt. According to the base value determinations it was 6′·0, but the figures in Table III suggest that 5′ would have been nearer the truth. The suspension gave way on September 13, so not unlikely, the change early in the month represented the giving way of some strand in the fibre. The base values obtained at Eskdalemuir in October, though rather fluctuating, showed no certain change until after the 21st, but later in the month there seemed a considerable progressive change, for which satisfactory allowance could not have been made. Thus the data in Table III are confined to the first 21 days, and for these a constant base value was assumed.

The Eskdalemuir instrument was overhauled during the first week of November. Absolute observations on the 7th, 8th, and 10th suggested a considerable rise in base value during these days. During the rest of the month the values, though fluctuating, showed little if any progressive rise. A constant base value was accordingly assumed for November from the 10th. In December the base values obtained near the beginning and end of the month did not differ much from one another, but the values obtained on the 16th and 17th differed by about 5′ from those obtained on the 18th, 23rd, and 24th, those on the first two days being low, and those on the last three days high as compared with either later or earlier observations. The curves, on the other hand, showed no sign of discontinuity during these changes. If we accepted the base values obtained on the 2nd, 3rd, 4th, 29th, and 30th as reliable, we should with these alone before us infer that the base value was nearly constant throughout the month ; but on this hypothesis, comparing results from the first three and last three days of the month, we get a rise of fully 6′ in the Eskdalemuir-Kew difference, and intermediate days suggest a nearly uniform rate of rise in this difference throughout the whole month. In view of the apparent incompatibility of such a result with Table II, and of the various inconsistencies, it was decided that no satisfactory

comparison of Eskdalemuir and Kew mean daily values was possible for the month of December.

So far as the other months are concerned there is little if any trace of systematic fluctuation in the Eskdalemuir-Kew difference, and the presence of disturbance seems to have little if any effect. The period was, however, on the whole free from large disturbances, and it would not be safe to assume that the mean daily Eskdalemuir-Kew difference may not on some individual highly disturbed days show a considerably larger departure from its mean monthly value than appears in any day in Table III.

So far, however, as days of characters 0 and 1 are concerned the divergence to be expected in the mean value for an individual day from the monthly mean value of the difference would seem to be of the order of 0′·5.

§ 6. Comparison of Midnight Values at Stonyhurst and Kew.

Even before the days of artificial disturbances, experience had shown that midnight is a convenient hour for the comparison of declination values at different stations. It is true that it is by no means the hour when natural disturbance is least frequent. Also near mid-winter midnight is an hour when the difference from the mean daily value is not small compared with the range of the diurnal inequality. But days of character 2 are generally in a small minority, and at mid-winter the range of the regular diurnal inequality on days of characters 0 and 1 is not large. The positive advantages of midnight are that the regular diurnal changes are then always slow, while the departure from the mean value for the day absolutely considered is at no season large, and in many months is very small. Except at times of active disturbance the D curve near midnight is very flat, so the precise method of measurement is of minor importance, and a slight time error, whether in the magnetograph clock itself or in the setting of the computer's scale, makes little difference.

In view of the base line changes, real or apparent, at Eskdalemuir it seemed preferable to use another station for the comparison of midnight values. This was fortunately possible owing to the loan of the Stonyhurst curves mentioned above. These enabled an extensive comparison to be made of midnight values at Stonyhurst and Kew, the results of which are given in Table IV. The quantity that appears in the table, in the columns headed B, represents the fluctuation in the excess of the value of D at 0h on the day stated at Stonyhurst over the corresponding value at Kew. The columns headed A give the character figures for the complete days taken from the Kew lists. It might have been fairer to take the mean of the character figures for the two days having the particular midnight in common.

Each month was treated independently, on the assumption that no fluctuation of base value occurred at either station throughout the month. On this hypothesis, for example, the excess of D at Stonyhurst over D at Kew at 0h was less on August 1st by 0′·7 and greater on August 31st by 0′·3 than it was on the average midnight of August.

The Stonyhurst magnetograph, like that at Kew, is a very old one, so that unsteadiness in the base-line value is unlikely to be serious. It is improbable of course that the base-line values were absolutely invariable throughout each month at either station. But such fluctuations as there may have been would at least be unlikely to lead to an underestimate of the fluctuations in the Stonyhurst-Kew difference.

The measurements made for the weekly tables were accepted for the Kew curves. The Stonyhurst curves were measured by myself. The blanks represent simply the absence of the corresponding Stonyhurst curves, this particular use not having suggested itself when the list of curves desired was sent to Stonyhurst.

TABLE IV.—STONYHURST-KEW MIDNIGHT VALUES (DEPARTURES FROM MONTHLY MEANS).

Date.	June.		July.		August.		September.		October.		November.		December.	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B
		′		′		′		′		′		′		′
1	..	..	..	..	1	−0·7	..	..	2	+2·5	0	−0·1	0	−0·4
2	..	..	..	..	1	+0·7	1	+0·3	2	+6·2	0	−0·3	0	−0·9
3	..	..	..	..	0	+0·1	0	−1·6	1	+5·2	0	−0·3	1	−0·7
4	..	..	..	..	0	−0·2	0	+1·3	2	+1·6	2	+0·2	1	+0·1
5	..	..	..	..	0	−0·3	0	+0·1	2	−0·6	..	..	1	−0·5
6	..	..	..	..	0	+0·1	1	+0·3	2	−1·3	..	..	0	+0·1
7	..	..	..	..	1	−0·2	1	+3·0	1	−0·9	..	..	0	−0·5
8	..	..	..	..	0	+0·1	0	−0·8	1	−1·4	..	..	1	−0·7
9	..	..	..	..	0	−1·3	1	−0·9	1	+0·1	..	..	0	+0·3
10	..	..	..	..	0	−0·9	1	−0·2	1	−0·6	..	..	0	0·0
11	..	..	0	−1·1	2	−0·8	0	+0·8	1	−1·2	2	−0·3	0	+0·6
12	..	..	0	−0·6	..	..	0	−1·2	0	−0·6	2	+0·4	1	+0·5
13	..	..	0	−0·7	..	..	1	+0·2	0	−1·7	0	+0·1	1	+1·1
14	..	..	0	−1·3	0	+0·1	1	−1·4	0	−0·9	0	−0·1	1	−0·1
15	..	..	0	..	0	+1·1	..	..	1	−0·3	0	+0·5	2	−0·4
16	..	..	..	..	1	+2·2	..	..	2	+1·3	2	−0·1	0	−1·1
17	..	..	1	−0·6	1	−0·2	..	..	2	−0·5	2	+1·2	0	−1·1
18	..	..	1	−0·1	0	+0·4	..	..	1	−1·0	2	−0·7	1	−0·4
19	..	..	0	−1·4	1	+0·2	..	..	0	−0·9	0	−0·2	1	+1·2
20	..	..	0	+0·3	1	+0·7	..	..	0	−1·2	0	−0·2	1	−0·3
21	..	..	0	−1·0	0	−1·1	..	..	0	−1·3	1	−0·5	1	−0·5
22	..	..	1	+1·1	0	−0·8	..	..	1	−0·8	1	−1·6	1	−0·6
23	..	..	1	−0·5	0	−1·5	..	..	1	−0·7	1	+0·2	1	+1·0
24	..	..	0	+2·3	0	−0·8	..	..	1	−0·9	1	+0·4	1	+1·2
25	..	..	0	+0·2	0	0·0	..	..	0	−0·5	..	..	1	+1·1
26	..	..	0	−0·3	..	..	..	..	1	+0·7	..	..	0	+0·6
27	0	−0·8	0	−0·2	..	..	..	..	1	−0·3	0	+0·8	..	..
28	0	−0·2	0	+0·5	0	+0·5	..	..	2	+0·2	0	+1·3	..	..
29	0	+0·7	0	+0·4	0	+1·9	..	..	..	..	..	..	..	..
30	0	+0·4	0	+1·2	0	+0·8	..	..	1	+0·1	..	..	..	..
31	..	..	0	+1·2	0	+0·3	..	..	1	0·0	..	..	..	..
Arithmetic Means	0·5		0·8		0·7		0·9		1·2		0·5		0·6	

On the average of the 139 days included in Table IV the departure of the difference between the midnight values from its monthly mean is a little under 0′·8. Only one month, October, gave an average departure in excess of 1′. The first three midnights of October, which were somewhat highly disturbed, present much larger departures from the mean than any others.

In the case of individual hourly curve values errors of measurement of course come in. Whilst the Kew readings were put down to the nearest 0′·1, and the Stonyhurst readings to the nearest 0·1 mm. (1 mm. = 1′·13), accuracy to nearer than 0′·2 can hardly be claimed in either case. Errors of reading, however, would be as likely to diminish as to increase the difference between the values of D at the two stations, and so should not sensibly influence the mean departures given in the last line of Table IV.

In view of what has been said above as to apparent differences between Kew and Eskdalemuir declinations during December, the fact that the mean figure for December in Table IV is similar to that for other months is reassuring.

§ 7. Daily Range in Eskdalemuir-Kew Declination.

Tables II and IV considered above may give too favourable an idea of the universal applicability of the *D* curves from a particular station. As a corrective, Table V shows for each day the range in the excess of *D* at Eskdalemuir over *D* at

Table V.—Daily Ranges in Eskdalemuir-Kew Declination.

Date.	July.		August.		October.		November.		December.	
	A	B	A	B	A	B	A	B	A	B
		′		′		′		′		′
1	0	3·9	1	2·0	2	10·5*i*	0	1·7	0	2·4
2	0	2·1	1	2·4	2	7·5	0	1·8	0	2·2
3	0	4·0*i*	0	3·6	1	4·7	0	0·8*i*	1	3·1
4	0	2·2*i*	0	2·2	2	5·0	..	..	1	3·0
5	0	1·4*i*	0	2·3	2	7·5	..	..	1	2·4
6	..	..	0	2·3	2	4·7	0	1·4*i*	0	1·9
7	0	2·7*i*	1	2·2	1	1·8	0	2·7	0	1·8
8	1	2·4*i*	0	1·7	1	2·9	0	1·3*i*	1	2·0
9	1	2·2*i*	0	1·6	1	3·7	0	1·9	0	1·6
10	0	3·2	0	2·1	1	1·8	0	1·2*i*	0	1·3
11	0	2·3	2	32·9	1	2·1	2	3·6*i*	0	1·5
12	0	2·4	2	11·0	0	2·4	2	4·6	1	2·6
13	0	3·4	0	1·8	0	2·6	0	1·2	1	2·6
14	0	2·4	0	2·6	0	2·8	0	1·2	1	4·0
15	0	2·1	0	2·1	1	2·7	0	1·3	2	6·1
16	0	1·5	1	4·2	2	4·4	2	3·6	0	1·7
17	1	7·0	1	3·6	2	3·9	2	4·8	0	1·4
18	1	3·7	0	2·4	1	3·1	2	3·3	1	4·4
19	0	2·1	1	3·3	0	2·1	0	1·5*i*	1	3·6
20	0	3·8	1	2·5	0	2·1	0	0·6*i*	1	3·6
21	0	2·3	0	2·7	0	1·7	1	4·0	1	2·2
22	1	4·5	0	3·5	1	1·7	1	4·2	1	2·4*i*
23	1	3·7	0	1·8*i*	1	4·4	1	3·2	1	2·5
24	0	1·1*i*	0	2·1*i*	1	1·3	1	2·7	1	3·7
25	..	..	0	1·8	0	2·1	1	1·5	1	1·8
26	0	2·5*i*	1	5·7	1	3·9	1	2·0	0	1·0
27	0	0·7*i*	0	2·8	1	4·4	0	1·1	0	1·5
28	0	1·9	0	3·6	2	7·2	0	1·7	0	1·9
29	0	2·6	0	3·2*i*	1	4·1	0	1·7	0	1·1
30	0	1·8	0	1·1	1	3·3	1	1·8	0	1·4
31	0	2·5*i*	0	2·0	1	4·0	..	..	0	1·3
Means from complete days	3·0		4·0		3·5		2·5		2·4	

Kew, i.e., it shows how much the largest excess of *D* at Eskdalemuir over *D* at Kew derived from hourly values exceeds the smallest excess found for the same day. The only assumption made as to base values is that the shift during a single day at either station may be neglected. The character figures appear in the columns headed A, the ranges in the columns headed B, the letter *i* being attached to the ranges in days that were incomplete. Only complete days were used when calculating the mean values of the ranges in the last line of the table.

As already explained, the original measurements at Kew for months prior to October were taken on smoothed curves. The Eskdalemuir-Kew differences based on these readings were, however, used only as a guide to the hours likely to supply the extreme values of the difference. The curves were then remeasured at the likely hours with the mean-value scale. All the measurements actually used in Table V thus represented mean hourly values.

If all the complete days included in Table V be arranged in three groups according to the character, the corresponding mean values of the ranges will be found to be 2′·1 for character 0, 3′·2 for character 1, and 7′·6 for character 2. As a rough approximation, half the range may be taken as the greatest departure made by the mean value of the Eskdalemuir-Kew difference for any one hour from its mean value for the whole day. The least range in Table V for any complete day is 1′·1, and the greatest 32′·9. No doubt if corresponding data were got out for a number of years ranges less than 1′·1 and ranges greater than 32′·9 would be encountered. It seems a natural inference from the table that in all survey and field work, where high accuracy is aimed at, recourse should be had to observatory records for information as to the magnetic character of the day of observation. The repetition of observations taken during disturbed times may be the lesser evil.

On quiet days, at least at hours when the regular diurnal variation changes are not rapid, the difference between instantaneous values at two stations should be similar in constancy to the difference between mean hourly values. But this is not the case on disturbed days.

§8. Irregular Movements at Eskdalemuir, Stonyhurst and Kew during 1919.

The investigation already referred to had shown a marked tendency for irregular *D* changes in 1908-9 to be larger at Eskdalemuir, Stonyhurst, and Falmouth than at Kew. Table VI shows the results of a similar enquiry for the later months of 1919.

Table VI.—Amplitudes of Irregular Movements at Kew, Eskdalemuir and Stonyhurst.

Date. 1919.	Characters.	Number of Movements.	Mean Amplitude at Kew.	Ratios of Amplitudes.		
				E/K.	S/K.	E/S.
June 28–29 ..	0 0	3	3′·6	1·32	0·84	1·57
July 12–13 ..	0 0	4	4′·3	1·36	0·84	1·61
,, 17–18 ..	1 1	11	7′·6	1·34	0·93	1·45
,, 18–19 ..	1 0	2	4′·0	1·40	0·89	1·58
,, 22–23 ..	1 1	10	9′·4	1·41	0·91	1·55
,, 23–24 ..	1 0	3	4′·4	1·47	0·87	1·69
,, 28–29 ..	0 0	1	6′·9	1·39	0·83	1·68
Sums and Means ..	.. ..	31	7′·1	1·38	0·91	1·53
August 1– 2 ..	1 1	3	6′·5	1·51	0·93	1·62
,, 5– 6 ..	0 0	2	3′·2	1·51	0·92	1·64
,, 7– 8 ..	1 0	3	4′·4	1·61	0·93	1·73
,, 8– 9 ..	0 0	1	2′·9	1·45	0·83	1·75
,, 15–16 ..	0 1	5	4′·2	1·50	0·89	1·68
,, 16–17 ..	1 1	2	5′·7	1·40	0·82	1·70
,, 18–19 ..	0 1	6	7′·8	1·44	0·83	1·74
,, 19–20 ..	1 1	7	5′·6	1·51	0·88	1·71
,, 20–21 ..	1 0	2	5′·2	1·33	0·82	1·63
,, 22–23 ..	0 0	2	4′·8	1·41	0·80	1·76
,, 28–29 ..	0 0	4	6′·3	1·21	0·79	1·54
Sums and Means ..	.. ..	37	5′·6	1·44	0·86	1·68

TABLE VI.—*cont.*

Date.	Characters.	Number of Movements.	Mean Amplitude at Kew.	Ratios of Amplitudes.		
				E/K.	S/K.	E/S.
September 2– 3 ..	1 0	3	11·2	1·32	0·90	1·47
,, 3– 4 ..	0 0	3	9·4	1·33	0·84	1·58
,, 5– 6 ..	0 1	2	9·4	1·45	0·87	1·66
,, 6– 7 ..	1 1	10	7·0	1·68	0·96	1·75
,, 9–10 ..	1 1	3	8·5	1·75	1·03	1·71
,, 10–11 ..	1 0	6	6·8	1·39	0·86	1·61
,, 11–12 ..	0 0	1	4·0	1·47	0·88	1·69
,, 12–13 ..	0 1	4	3·1	1·42	0·93	1·53
Sums and Means ..	.. ..	32	7·3	1·51	0·92	1·64
October 1– 2 ..	2 2	9	13·8	2·09	1·02	2·04
,, 3– 4 ..	1 2	6	6·6	1·56	0·87	1·80
,, 4– 5 ..	2 2	20	10·2	1·80	1·12	1·60
,, 5– 6 ..	2 2	12	10·6	2·06	1·45	1·42
,, 6– 7 ..	2 1	4	6·3	1·50	0·96	1·57
,, 7– 8 ..	1 1	2	5·9	1·45	1·18	1·23
,, 8– 9 ..	1 1	8	6·7	1·36	1·05	1·29
,, 10–11 ..	1 1	5	5·0	1·33	1·20	1·11
,, 15–16 ..	1 2	10	7·7	1·41	1·18	1·20
,, 16–17 ..	2 2	5	4·6	1·48	1·32	1·12
,, 17–18 ..	2 1	2	12·7	1·51	1·22	1·24
,, 18–19 ..	1 0	2	14·8	1·24	1·10	1·12
,, 22–23 ..	1 1	4	8·7	1·46	1·13	1·29
,, 23–24 ..	1 1	4	4·9	1·44	1·26	1·14
,, 26–27 ..	1 1	4	10·8	1·53	1·28	1·20
,, 28–29 ..	2 1	5	13·8	1·32	..	..
,, 30–31 ..	1 1	2	7·2	1·46	1·13	1·30
Sums and Means ..	.. ..	104	9·1	1·68	1·16	1·47
November 2– 3 ..	0 0	3	5·4	1·37	0·96	1·44
,, 11–12 ..	2 2	2	11·6	1·41	1·02	1·38
,, 16–17 ..	2 2	6	5·9	1·53	0·92	1·68
,, 17–18 ..	2 2	5	9·4	1·39	0·93	1·50
,, 21–22 ..	1 1	6	7·7	1·36	0·90	1·52
,, 23–24 ..	1 1	2	7·8	1·45	0·87	1·67
,, 25–26 ..	1 1	4	4·7	1·32	0·81	1·63
Sums and Means ..	.. ..	28	7·2	1·41	0·92	1·54
December 2– 3 ..	0 1	2	3·4	1·36	0·83	1·65
,, 3– 4 ..	1 1	4	4·2	1·53	0·89	1·71
,, 4– 5 ..	1 1	2	4·5	1·34	0·84	1·59
,, 8– 9 ..	1 0	3	9·4	1·56	0·90	1·73
,, 12–13 ..	1 1	5	3·2	1·32	0·85	1·54
,, 13–14 ..	1 1	3	4·9	1·33	0·89	1·49
,, 14–15 ..	1 2	7	7·7	1·29	0·92	1·39
,, 15–16 ..	2 0	5	9·2	1·98	1·14	1·74
,, 18–19 ..	1 1	5	7·2	1·28	0·80	1·61
,, 19–20 ..	1 1	3	5·7	1·35	0·82	1·65
,, 20–21 ..	1 1	7	5·4	1·36	0·87	1·57
,, 21–22 ..	1 1	2	10·4	1·43	0·88	1·61
,, 22–23 ..	1 1	2	10·0	1·40	0·87	1·62
,, 23–24 ..	1 1	7	4·1	1·52	0·94	1·61
,, 24–25 ..	1 1	3	4·5	1·21	0·78	1·56
Sums and Means ..		60	6·1	1·45	0·91	1·60

Most of the movements measured were oscillations occupying no very long time. The great majority referred to hours near midnight, and few if any to hours near noon. There were several reasons for this. Declination disturbance is rare near noon. Also irregular movements during the day hours are more affected by the regular diurnal variation than those occurring during the night. Lastly the artificial disturbances to which Kew is now exposed introduce undesirable uncertainty into measurements of short period oscillations during the busy hours of the day. The measurements have thus been grouped under the night on which they occurred. Usually some of the movements preceded and others followed midnight, but that was not always the case. The character figures given refer to the days preceding and following the midnight in question. The values of the ratios E/K (Eskdalemuir movement ÷ Kew movement), S/K (Stonyhurst movement ÷ Kew movement), and E/S (Eskdalemuir movement ÷ Stonyhurst movement) were got for each night by dividing the aggregate of the movements at the one station by the corresponding aggregate at the other. Similarly the aggregate of the movements for the month were used for the figures relating to the month. Thus the contribution of any movement to the monthly figure was the same whether many or few movements occurred on the same night.

As a rule very small movements were not selected when others were available. From the practical point of view, the phenomena exhibited by small movements are of minor importance. Further the probable error of measurement is as great for a small as for a large movement, so that the percentage error in the small movement is undesirably great. Another practical consideration is that when aggregates are used for comparison small movements tend to be swamped.

To get absolutely representative results, it would be desirable to measure all irregular movements, or all exceeding a certain size. This was impossible in the present case, owing to artificial disturbances at Kew and to interruptions of the Eskdalemuir records. But considerations of time also led to the omission of many movements, especially in months when there was a wide choice. In the selection regard was had more especially to the definiteness of the beginning and end of the movement, and the goodness of the trace.

As regards Eskdalemuir and Kew, the outstanding features in Table VI are the uniformity in the values obtained for E/K during most of the months, and the smallness of the values compared with those obtained for 1908–9. Measurements were made on twenty-six nights during the months of June, July, August and September, and the values obtained for E/K varied only between 1·21 and 1·75, the great majority lying between 1·30 and 1·50. The October values of E/K fluctuate more, some of the values for the early part of the month being much above the average. But even the largest of these, 2·09 on October 1–2, is less than the mean value obtained in 1908–9. The values obtained for E/K in November and December, with the exception of the value for December 15–16, are similar to those found for the summer months. Taking all the observations of Table VI, we find for the mean E/K the value 1·54, as compared with the value 2·14 derived from 433 movements during 1908 and 1909. The highest monthly value of E/K in Table VI, viz., 1·68 for October, is less than the smallest, 1·83, obtained for any month in 1908–9.

The possibility of some mistake as to the Eskdalemuir scale value naturally suggested itself. It would require, however, to be a very big mistake to explain

the difference between 1919 and 1908–9, and anything but a trifling mistake seems ruled out by the inequality results in Table I. Independent confirmation, however, of so unexpected a result was clearly desirable, and it was for this object that the loan of the Stonyhurst curves was obtained. It was anticipated that, as in 1908–9, movements at Stonyhurst would be intermediate in size between those at Eskdalemuir and at Kew, and it was expected that the ratio S/K would be reduced somewhat in the same proportion as E/K. The results for October are something like what was expected, but in all the other months the monthly value of S/K is actually less than unity. This, moreover, is true of the great majority of individual nights. In fact, of the forty-eight nights during June, July, August, September, November and December on which movements were measured, only three gave values for S/K exceeding unity. It is true, that when we take all the months, the excess of the Stonyhurst movements during October is so substantial as to bring the mean value of S/K up to 1·01, but this compares with 1·68, the mean obtained for 1908–9. A reduction in the value of E/K might be explained by a movement towards the north-west of the electrical currents causing the magnetic changes, but this would not account for S/K becoming less than unity.

§ 9. Amplitudes of irregular Movements at Falmouth and Kew, 1908 to 1913.

The extraordinary difference between 1919 and 1908–9 suggested the investigation of some of the intermediate years. The Falmouth curves being at hand, it was decided to extend the comparison made between Falmouth and Kew for 1908–9. Tables VII and VIII include the results obtained from January 1908

Table VII.—Amplitudes of Irregular Movements at Kew and Falmouth.

Month.	Number of Nights.	Number of Movements.	Mean Amplitude at Kew.	Values of F/K.		
				Greatest.	Mean.	Least.
1908						
January	11	38	4·7	1·52	1·26	0·91
February	9	37	5·9	1·40	1·16	0·99
March	11	56	8·4	1·24	1·15	1·01
April	8	40	6·8	1·22	1·04	1·00
May	9	38	6·4	1·06	1·03	0·91
June	7	23	4·2	1·02	0·97	0·90
July	7	23	4·2	1·27	1·10	0·95
August	11	55	7·5	1·24	1·06	0·86
September	15	120	11·1	1·47	1·14	0·95
October	4	23	4·6	1·34	1·27	1·23
November	15	92	3·6	1·40	1·23	0·93
December	7	20	2·2	1·37	1·24	0·89
1909						
January	5	56	5·0	1·35	1·21	1·14
February	4	44	5·5	1·30	1·19	1·16
March	5	103	6·0	1·07	0·99	0·89
April	2	18	3·8	..	0·98	..
May	2	33	8·7	..	1·01	..
June	2	25	3·5	..	1·08	..
July	1	11	4·0	..	1·20	..
August	4	49	5·0	1·14	1·10	0·96
September	4	44	6·3	1·19	1·15	1·11
October	9	80	5·9	1·44	1·11	1·08
November	9	31	5·0	1·43	1·19	1·07
December	14	70	4·5	1·58	1·35	1·02

[*continued.*

TABLE VII.—*cont.*

Month.	Number of nights.	Number of Movements.	Mean Amplitude at Kew.	Values of F/K.		
				Greatest.	Mean.	Least.
1910			′			
January	8	37	5·4	1·50	1·23	1·12
February	11	32	5·5	1·31	1·16	1·01
March	14	64	7·2	1·28	1·18	0·95
April	11	42	6·6	1·21	1·07	0·94
May	8	28	5·2	1·30	1·16	0·97
June	5	25	10·4	1·20	1·02	0·96
July	5	17	7·0	1·35	1·12	0·90
August	12	45	6·6	1·38	1·18	1·08
September	8	40	9·4	1·20	1·07	0·94
October	14	77	8·1	1·28	1·12	1·02
November	11	59	3·8	2·81	1·72	1·14
December	11	46	4·6	2·63	1·65	1·01
1911						
January	9	50	5·4	2·40	1·40	1·17
February	8	42	8·8	1·31	1·16	1·10
March	10	50	6·1	1·58	1·27	1·11
April	7	28	9·0	1·36	1·18	1·08
May	10	31	5·7	1·31	1·16	1·01
June	5	25	5·8	1·12	1·00	0·93
July	6	27	6·6	1·23	1·03	1·03
August	7	27	5·8	1·38	1·03	1·03
September	9	41	5·9	1·16	1·04	0·88
October	11	42	4·9	1·56	1·16	1·05
November	7	31	4·7	1·52	1·44	1·05
December	6	32	5·3	1·82	1·54	1·07
1912						
January	11	29	1·8	2·78	1·67	0·93
February	7	21	4·9	1·09	0·96	0·89
March	6	26	6·1	1·04	0·95	0·90
April	4	18	6·4	1·05	0·98	0·92
May	5	24	5·9	1·07	1·00	0·96
June	3	10	4·6	1·19	1·09	1·06
July	5	20	4·4	1·11	1·00	0·93
August	7	30	5·8	1·16	0·99	0·90
September	5	21	7·8	1·00	0·97	0·89
October ..	6	27	10·0	1·00	0·96	0·86
November	7	24	5·8	1·05	0·94	0·88
December	8	34	6·8	1·03	0·98	0·89
1913						
January	7	26	6·2	1·02	0·97	0·86
February	5	11	4·9	1·04	0·98	0·92
March	10	27	6·3	1·05	0·97	0·88
April	5	18	8·9	1·07	0·98	0·89
May	1	8	8·1	..	1·04	..

to May 1913, when registration ceased at Falmouth. The earlier investigation included the months October 1908 to December 1909. No additional measurements were made for 1909, but further movements were measured to represent the first nine months of 1908. Altogether some 1,600 movements were measured at Kew and Falmouth, all measurements being repeated after an interval of time as a check.

The procedure was the same as in the case of Kew and Eskdalemuir. The movements belonging to a single night were grouped together, and the aggregate was used for calculating the value of F K (i.e. Falmouth movement ÷ Kew movement).

To economise space, only the largest and least of these nightly ratios are shown in Table VII along with the mean value of F/K for the whole month. This monthly mean represents the ratio obtained by dividing the aggregate of all the Falmouth movements during the month by the corresponding aggregate for Kew. Only the mean is given in May 1913, and some months of 1909, owing to the restriction of data. This restriction was unavoidable in May 1913. The choice of days in 1909 might have been widened, but the results having been already published for that year, a change seemed undesirable. The reduction in the number of movements measured in 1912 and 1913 was mainly due to the fact that owing to the absence of disturbance in these years suitable movements were difficult to find. Not a few otherwise appropriate movements in all the years were ruled out owing to artificial disturbance at Falmouth. The magnetographs there were satisfactorily remote from electric trains or trams, but the magnetograph room was in a dwelling-house, and not far from a public road.

TABLE VIII.—IRREGULAR MOVEMENTS.

Year.	Monthly Values of F/K.												Yearly Data.		
	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean.	Number of	
														Nights.	Move-ments.
1908 ..	1·26	1·16	1·15	1·04	1·03	0·97	1·10	1·06	1·14	1·27	1·23	1·24	1·13	114	565
1909 ..	1·21	1·19	0·99	0·98	1·01	1·08	1·20	1·19	1·15	1·11	1·19	1·35	1·12	60	564
1910 ..	1·23	1·16	1·18	1·07	1·16	1·02	1·12	1·18	1·07	1·12	1·72	1·65	1·20	118	512
1911 ..	1·40	1·16	1·27	1·18	1·16	1·00	1·03	1·03	1·04	1·16	1·44	1·54	1·20	95	426
1912 ..	1·67	0·96	0·95	0·98	1·00	1·09	1·00	0·99	0·97	0·96	0·94	0·98	1·00	74	284
5-Year Mean	1·35	1·13	1·11	1·05	1·07	1·03	1·09	1·07	1·07	1·12	1·30	1·35			

The mean monthly values of F/K are juxtaposed in Table VIII. In 1910 and 1911 no mean monthly value of F/K falls short of unity, and in 1908 there is only one month in which this happens. But in nine consecutive months from August 1912 to April 1913,* the mean value lies between 0·94 and 0·99. The narrowness of the limits between which F/K lies during these latter months is truly remarkable. From October 1910 to May 1911, movements were measured on eighty nights, and on every night the aggregate was larger for Falmouth than for Kew. November and December 1910 and January 1911 were the months of this period in which the greater amplitude of the Falmouth movements was most striking. The last three months of 1911 also showed persistently high values of the ratio F/K. Some exceptionally high values presented themselves in January 1912 and the mean value for that month is second only to the value for November 1910, but the average size of the movements is so small that the results possess less significance than would otherwise be the case.

The 1908–9 results had suggested " that the amplitude at Kew relative to the amplitudes at the other stations is distinctly greater in summer than in winter, but it was considered that several years results . . . would be necessary to put such a conclusion adequately to the test." The collection of the monthly values of F/K in Table VIII was principally intended for the application of this test. The values in the last line of the table—which are the arithmetic means from the five months of the same name—confirm the reality of an annual variation in the value

* The results for months of 1913 are not included in Table VIII.

of F/K. The excess in the values for the midwinter months over those for the midsummer months seems decisive. It would require, however, a considerably larger number of years to determine with certainty the months in which the largest and least values present themselves.

The mean values ascribed to the individual years were obtained from the aggregates of the movements at the two stations for the whole year. The difference between 1912 and the two preceding years is conspicuous. Whatever may have been the case at Eskdalemuir and Stonyhurst, 1908 and 1909 do not present outstanding excesses in the movements at Falmouth over those at Kew.

§ 10. Inequality Ranges at Falmouth and Kew.

Before passing from the subject of the marked annual variation shown in Table VIII, it seemed desirable to ascertain whether it was a phenomenon confined to irregular movements. To test this point use was made of the diurnal inequalities derived for Falmouth and Kew from the international quiet days. Each monthly diurnal inequality range at Falmouth was divided by the corresponding range at Kew, and the results are given in Table IX for *H* as well as *D*. It was not thought worth while to eliminate the non-cyclic changes, which had not been eliminated in the annual tables as published.

The figures in the five-year means in Table IX are arithmetic means of those for the individual years, and those in the last column are the arithmetic means of the figures for the individual months of the year. The result obtained from the published *H* data for September 1910 has not been used. Its large size, 2·07, and the small value of the Kew range, roused suspicion. The quiet day Kew curves for the month, on being consulted, were found to be unusually flat, but not otherwise abnormal; but on looking through the other curves it was noticed that when any considerable movement occurred it took place not continuously but in jerks. This went on throughout the month and until October 6, when a note on the sheet explained that the magnet had been found to be grazing the damper. The presumption is that the defect had been present throughout at least the greater part of September.

The *D* and *H* inequality ranges in Table IX both show clearly the annual period in the ratio which was exhibited by Table VIII. It is rather singular that

Table IX.—Inequality Ranges. (Falmouth Range) ÷ (Kew Range).

Element	Year.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly Mean.
D	1908	1·24	1·16	1·41	0·96	0·99	0·92	0·97	1·04	1·23	1·07	1·07	1·18	1·10
	1909	1·20	1·10	1·15	1·03	0·98	1·09	1·11	0·98	1·16	1·09	1·14	1·11	1·10
	1910	1·44	1·18	1·03	1·00	1·04	1·08	1·00	1·10	1·08	1·11	1·10	1·24	1·12
	1911	1·56	1·11	1·14	1·07	0·97	1·01	0·96	0·99	1·08	1·18	1·58	1·32	1·16
	1912	1·16	0·97	0·96	0·92	0·89	0·99	0·89	0·96	0·94	0·98	1·02	0·94	0·97
5-Year Mean ..		1·32	1·10	1·14	1·00	0·97	1·02	0·99	1·01	1·10	1·09	1·18	1·16	1·09
H	1908	1·00	1·17	0·94	0·88	0·88	0·95	1·00	1·00	1·00	0·97	1·00	1·12	0·99
	1909	1·18	0·60	1·15	1·00	1·03	1·02	1·05	1·00	1·03	1·00	1·12	1·31	1·04
	1910	1·23	1·42	1·04	1·11	1·09	0·98	1·03	1·12	..	1·12	1·22	1·60	1·18
	1911	1·63	1·49	1·04	1·09	1·00	0·90	1·01	0·77	0·97	1·09	1·03	0·77	1·07
	1912	0·75	0·76	0·98	0·97	0·99	0·92	0·98	1·00	0·98	1·04	1·24	0·87	0·96
5-Year Mean ..		1·16	1·09	1·03	1·01	1·00	0·95	1·01	0·98	1·00	1·04	1·12	1·13	1·04

this was not noticed before in my discussion of Kew and Falmouth quiet day inequalities. The epochs considered, however, were not quite the same for the two stations,

being 1890 to 1900 for Kew, but 1891 to 1902 for Falmouth. Irregularity in the hours of maximum and minimum in different years tends in such a case to reduce the range of the composite inequality, and the winter months may have suffered more from this at Falmouth than at Kew. Whatever the reason, if we divide the monthly inequality ranges for Falmouth from the quiet days of 1891 to 1900 by the corresponding Kew ranges from the quiet days of 1890 to 1900, while we do get the ratio bigger in the winter than in the summer months, the annual variation in the ratio is less conspicuous than in Table IX. A point to remember is that the inequality range is so small near midwinter, absolutely considered, that a difference of 20 per cent. between Falmouth and Kew is but a small quantity. Small differences of this kind are apt to be overlooked unless one happens to observe a persistency in one direction. The significant thing for the present research is that the annual variation in the ratio borne by movements at Falmouth to corresponding movements at Kew is, to a certain extent at least, common to regular and irregular movements.

Apart from the annual variation in F/K there seems a certain amount of parallelism between the monthly fluctuations shown in Tables VIII and IX, but it is not very close. Possibly the parallelism would have been closer if the inequality ranges had been derived from all days of the month. If the quiet days in a particular month happened to come from the earlier part of the month, and the irregular movements from the later part, a relation between the amplitudes of the two species of movements would seem less likely than a relation between the irregular movements of that month and the regular movements of the subsequent month.

§ 11. The Influence of the General Magnetic Character of the Day on the Amplitude of irregular Movements.

A related question is whether the ratio between irregular movements at Kew and Falmouth varies with the magnetic character of the day. The years 1912 and 1913 were very quiet, and the low values obtained for F/K after January 1912 are suggestive that with decrease of disturbance the amplitude of irregular movements at Falmouth may fall as compared with Kew. Table X presents the evidence available on this question. It employs the international character figures assigned at De Bilt. The objection may be raised that these figures differ from the character figures used earlier in the paper and take account of the other elements as well as *D*. On the other hand, it will be generally recognised that the international figures are the most authoritative which can be used, and they existed ready to hand for the years 1908 to 1913 (though not for 1919). As explained above, the movements employed in Table VII were grouped for twenty-four-hour periods commencing and ending at Greenwich noon. To get corresponding character figures, an arithmetic mean was taken from the two Greenwich days having the centre of the twenty-four-hour period concerned as their common midnight. Characters are given in the international list to 0·1, so the means formed for the present enquiry went to 0·05. The nights in which the movement occurred were arranged in six groups, according to the character figures. The limits defining the groups are given in the table. The movements included in the first group were originally destined for two groups, the first to include characters from 0·0 to 0·2, but there proved to be only four movements—from two days of January 1912—answering to character figures less than 0·25. The

fact was not wholly unexpected. The similarity of the irregular movements at British stations rendered it practically certain that they are widely felt, at least in Europe. Thus a day on which several irregular movements occurred would be certain to have a 1 assigned to it at a good many stations, and the international character figure, being the arithmetic mean of those assigned at the co-operating stations, would thus be unlikely to secure the small values 0·0, 0·1 or 0·2 usually found on the international quiet days. Still, the scarcity of small character figures on the days containing the irregular movements was greater than expected.

To eliminate, as far as possible, the effects of the seasonal variation of F/K, the months were arranged in three seasons: winter (January, February, November and December), equinox (March, April, September and October), and summer (May to August). If the movements had been sufficiently numerous the twelve months might with advantage have been treated separately.

The only way in which the magnetic character makes its presence clearly felt in Table X is in the increase in the absolute size of the movement as the character figure rises. This phenomenon was practically certain *a priori*.

TABLE X.—AMPLITUDES OF IRREGULAR MOVEMENTS AND INTERNATIONAL CHARACTER FIGURES.

International Character.	Year.	WINTER.			EQUINOX.			SUMMER.		
		No.	K.	F/K.	No.	K.	F/K.	No.	K.	F/K.
0·0 to 0·45	1910	2	2·7	1·13	..	..	..	..	..	..
	1911	4	3·1	1·21	8	3·0	1·34	8	5·0	1·11
	1912	23	2·2	1·09	8	5·7	0·97	2	4·8	0·93
	3 Years	29	2·4	1·11	16	4·4	1·10	10	5·0	1·08
0·50 to 0·70	1910	8	5·7	1·21	15	4·6	1·07	12	4·4	1·19
	1911	19	4·9	1·31	27	4·1	1·18	9	4·1	1·15
	1912	32	4·8	1·07	5	4·2	0·95	4	3·6	1·16
	3 Years	59	5·0	1·17	47	4·3	1·12	25	4·2	1·17
0·75 to 0·95	1910	70	4·1	1·44	19	7·7	1·03	32	6·3	1·17
	1911	47	4·7	1·31	17	5·4	1·07	20	4·8	1·06
	1912	23	5·5	1·04	25	6·7	0·93	33	4·9	1·00
	3 Years	140	4·5	1·32	61	6·6	1·00	85	5·4	1·09
1·00 to 1·20	1910	57	4·6	1·43	91	5·9	1·16	42	6·4	1·12
	1911	46	5·6	1·47	40	5·4	1·24	39	6·2	1·05
	1912	30	6·5	0·99	25	7·1	0·95	32	6·0	1·00
	3 Years	133	5·4	1·33	156	6·0	1·14	113	6·2	1·06
1·25 to 1·45	1910	33	5·8	1·36	79	9·8	1·08	25	10·9	1·06
	1911	6	5·8	1·55	31	6·6	1·12	22	6·6	1·09
	1912	..	..	..	29	10·2	0·98	13	5·4	1·03
	3 Years	39	5·8	1·39	139	9·2	1·07	60	8·2	1·06
1·50 to 2·00	1910	4	6·4	2·04	19	11·1	1·22	4	7·0	1·09
	1911	33	10·1	1·24	38	9·4	1·16	12	7·7	0·98
	1912	..	..	..	..	..	..	..	..	..
	3 Years	37	9·7	1·29	57	10·0	1·19	16	7·5	1·01

§ 12. CONCLUSIONS.

The winter figures in Table X are a little suggestive of a tendency in the value of F/K to increase as the character rises, but they are certainly not decisive on this point. In the other seasons the fluctuations in the values of F/K look quite fortuitous.

All the days in the last group, and many of those having characters between 1·25 and 1·45, would ordinarily be described as days of magnetic storm. It follows that, so far at least as Falmouth and Kew are concerned, geographical position exerts practically the same influence on the amplitude of irregular movements during magnetic storms and during times of minor disturbances. During an active magnetic storm oscillations varying in duration from a fraction of a minute to a number of minutes are superposed on slower changes, which may show a general tendency for the element to increase or diminish for a number of hours. The movements dealt with here are, mainly at least, of the former class. Different sources may contribute to the movements in magnetic storms, and the contributions from the different sources may obey different laws. But, however that may be, the results obtained from Eskdalemuir, Stonyhurst, Falmouth and Kew curves place it beyond a doubt that an important part of the irregular movements depends on causes which, unlike the geographical co-ordinates of the station, or the position of the "magnetic axis" of the earth, fluctuate markedly with time. It is desirable to emphasise this fact, because several modern theorists of repute seem to assign a prominence—probably undeserved in this connection—to the magnetic axis (axis of first zonal harmonic in the Gaussian analysis). At a distance of several earth's radii above the surface the first zonal harmonic may be altogether dominant. But the electrical currents to which the principal part of magnetic storms are due are certainly not at heights of this order. They may not be identical with the auroral discharges, the heights of which, according to Störmer, Vegard and Krogness, are mainly between 90 and 200 kilometres, but the presumption is that the heights of the two species of currents —if they are distinct—are not of different orders. At auroral heights the first order harmonic should not in any case be so dominant as to justify the neglect of terms of the higher orders. Also the Gaussian results are really based on observational data in which latitudes greater than 60 deg. north or south are practically unrepresented. So far as the Arctic and Antarctic regions or the auroral belts are concerned, the magnetic field within 200 kilometres of the earth's surface cannot safely be assumed to be identical with the Gaussian field even to a first approximation.

The chief practical deductions from the present investigation are as follows: if accuracy to 0′·5 or even 1′·0 is essential, it cannot be assured by referring individual observations, however accurate, taken in the field, to the records of a distant observatory. But it can fairly be secured by a succession of observations taken on the same day, or at a suitable hour of several days, provided the days are magnetically quiet. If the observations are taken during the day hours, more especially in summer, the accuracy will be improved if allowance is made from the regular diurnal inequality for the difference of local time between the field station and the observatory.

If high accuracy is aimed at, observations taken at times of oscillatory movements—the existence of which is at once apparent on consulting observatory records —had better be scrapped, because the ratio of the amplitudes of such movements at any two stations not close together is not constant, and the laws of variation of the ratio are complex and imperfectly ascertained. It is thus important that for

survey work of the highest accuracy the records of at least one observatory should be consulted.

If accuracy to 10′ suffices, the value of D can generally be secured from a single good observation by reference to the records of even a distant observatory, but observations taken during a time of short period oscillations had better be discarded, especially if the exact time of observation be not very accurately known. Observations taken during an active magnetic storm should never be relied on if it can possibly be helped. It is believed that the probability of large departures from the normal declination increases throughout the British Isles with increasing latitude and increasing Westerly longitude, but further information on this point is desirable.

The irregular declination movements recorded at any two stations within the British Isles show a general similarity which precludes their being assigned as a rule to any purely local cause. If earth currents be the immediate cause, they must either be mainly at a considerable depth, comparable with the height of aurora, or their principal features must be independent of the surface configuration. Whilst the ratio of the irregular movements at two distant stations sometimes varies markedly for successive oscillations, and is never more than approximately constant for a single day, it often shows a tendency to retain a roughly constant value for a good many days, sometimes even for a good many months. The mean monthly value of the ratio shows, however, an annual variation, and it may be somewhat widely different for the same month of two consecutive years. Again, the amplitude at a station may at times be less than at either of two other stations between which it lies. Thus we are not yet in a position to infer the amplitude of irregular movements in the field from those at even two (or more) remote stations.